APPENDIX E
RISK ASSESSMENT FOR SPILL PROGRAM DESCRIBED IN 2000 DRAFT BIOLOGICAL OPINION

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E.1 SUMMARY

This paper addresses the 120% dissolved gas ceiling in light of the findings of the "Spill and 1995 Risk Management" report (1995 report) prepared by the region's fishery agencies and tribes (WDFW et al. 1995), the findings of research before and during implementation of the 1995 FCRPS Biological Opinion, and the results of the physical and biological monitoring program conducted from 1995 to the present. Two spill program scenarios are evaluated using the SIMPAS model, which compares the potential juvenile salmonid survival improvement due to increased spill against the risks of increasing total dissolved gas above the 110% water quality standard. The National Marine Fisheries Service (NMFS) concludes in this updated assessment that the risk associated with a managed spill program to the 120% total dissolved gas (TDG) level is warranted by the projected 4% to 6% increase in system survival of juvenile salmonids. Recent research and biological monitoring results support the findings of the 1995 report, which predicted that TDG in the 120%-to-125% range, coupled with vertical distribution fish passage information indicating that most fish migrate at depths providing some gas compensation, would not cause juvenile or adult salmon mortalities exceeding the expected benefits of spillway passage. NMFS finds little evidence that this expected survival improvement would be reduced by mortality related to gas bubble trauma (GBT). NMFS also concludes that physical and biological monitoring of GBT signs can continue to be used to indicate dissolved gas exposure in adult and juvenile salmon migrants.

E.2 INTRODUCTION AND BACKGROUND

Risk assessment is the comparison of alternative paths of action to determine the probability of an adverse outcome. The 1995 report was based on a risk model described by Rowe (1997). In that model, risk is characterized and managed by identifying the hazards and the degree of exposure to those associated with different paths of action. In the 1995 report, two paths of juvenile fish passage were compared: a) juvenile fish through turbines, where they are subjected to physical hazards, changes in pressure, etc., or, b) routing them over project spillways by increasing the volume of water spilled. The main hazard involved in the second alternative is the potential effect of dissolved gas supersaturation and the debilitating, and potentially lethal, GBT. The 1995 report found that, within limits, spill had merit compared with turbine passage. As a result of that report, NMFS recommended spill to achieve 80% fish passage efficiency (FPE) up to a gas level of 120% in the tailrace (and 115% in the forebay) at mainstem hydroprojects where juvenile salmon pass.

The region now has 5 years' experience in implementing the spill program recommended by the 1995 FCRPS Biological Opinion. Additional dissolved gas research has been conducted. Moreover, 5 years of physical and biological monitoring results are now available to characterize the results of the spill program adopted by NMFS in 1995. Finally, the NMFS SIMPAS model, used to estimate the projected survival effects of management alternatives, was updated in 2000 with the most recent quantitative input to various fish passage functions. The model allows predicting the project and system survival effects for listed juvenile salmonids at different spill levels. Here, we investigate the risk to salmonids of TDG levels greater than the 110% water quality standard. The investigation does not assess risk to other aquatic species. For further information on that topic, see Schrank et al. (1996 and 1997); Ryan and Dawley (1998); and Ryan et al. (2000).

E.2.1 1995 Spill and Risk Management Report

In 1995, a group of the region's agencies and tribes developed the 1995 report, which evaluated the risks of alternate strategies for the passage of juvenile salmonids at hydroelectric projects in the Columbia River basin. The two main passage routes scrutinized were passage through turbines and voluntary spill at the FCRPS projects. The work was done jointly by technical staffs of the Columbia River Intertribal Fish Commission, the Idaho Department of Fish and Game, the Oregon Department of Fish and Wildlife, and the Washington Department of Fish and Wildlife. Also contributing to the report were the U.S. Fish and Wildlife Service, NMFS, and the Fish Passage Center.

Spill has long been known as a valid and relatively safe strategy for increasing passage efficiency and improving the survival of juvenile migrants. However, spill generates dissolved gas supersaturation, which represents a risk to fish if the gas level is too high. When the 1995 report was written, there had already been approximately 30 years of laboratory and field research on the subjects of spill, TDG production, the biological effects of dissolved gas supersaturation, and other hydroelectric project effects on juvenile and adult salmonid passage. The 1995 report reviewed the research on spill and its effect on dissolved gas generation and subsequent GBT and mortality in fish. Relative risks were then mathematically assessed on the basis of an analysis of quantitative information concerning direct fish mortality from both turbine and spill passage. The 1995 report concluded that, as long as spill-generated TDG levels did not exceed 120% to 125% supersaturation, the risk of passing juvenile salmonids through the spillways remained lower than the risk of passing juveniles through turbines. The 1995 assessment also indicated that the same level of TDG would not harm adult salmon.

E.2.2 NMFS 2000 Approach

The dissolved gas water quality standard was established in the 1970s by the U.S. Environmental Protection Agency (EPA). The standard is enforced by the water quality agencies in each state. The dissolved gas standard is limited to a dissolved gas supersaturation of 110%. It applies to all fish and aquatic life and incorporates a margin of safety. Since the implementation of the first biological opinion, the states recognized the value of spill to increasing the survival of downstream migrants. They have, therefore, granted temporary waivers of the TDG standard to a level of 115% TDG in project forebays and 120% TDG in tailraces during the juvenile migration season. The pertinent question in this risk analysis concerns the increase in juvenile survival represented by the additional 5% to 10% of dissolved gas permitted by the states' temporary waiver limits.

NMFS employed the SIMPAS model to evaluate the potential increase in juvenile survival due to the difference in spill levels generating TDG of 110% or 120% supersaturation. The SIMPAS model includes all the current information on species-specific fish passage parameters: spill efficiency; fish guidance efficiency; spill/gas caps, turbine, spillway, sluiceway, and bypass survivals; and diel passage patterns.[1]

The increase in survival due to the added spill is compared with the risk potential due to the added 5% to 10% of TDG. The results of 5 years of monitoring TDG levels (during the 1995-to-1999 spill seasons) and the biological reactions in the juvenile migrant population detected by the monitoring program are reviewed. The results of research during the same period are also reviewed to validate the monitoring methods and to verify the assumptions of the SIMPAS modeling.

E.3 1995 TURBINE VERSUS SPILL MORTALITY RISK ASSESSMENT

E.3.1 Juvenile Salmonid Assessment

The hydroelectric projects on the Columbia and Snake rivers impede salmonid migrations (Raymond 1969, 1979). Passage of juveniles through turbines, bypass systems, and spill represents sources of injury and mortality (NMFS 2000a). For example, recent NMFS studies of turbine survival for yearling chinook in the Snake River produced estimates of 92.0% in 1993, 86.5% in 1994, and 92.7% in 1995 at Little Goose, Lower Monumental, and Lower Granite dams. Steelhead survival from turbine passage at Little Goose in 1997 was 93.4% (Muir et al., In review: No. Am. J. Fish. Mgt.).

The most benign method for improving passage is to pass fish over the project, through the spillway, and avoid the powerhouse altogether (NMFS 2000a; ISAB 1999). The range of spillway mortality for standard spillway structures is 0% to 2% (Whitney et al. 1997).

[1]For a more complete description of the SIMPAS model and a listing of its passage parameters, see Appendix D.

The 1995 report assessed the risks of turbine passage and spill as alternate routes of passage through FCRPS hydropower projects. Specifically, the 1995 assessment compared the anticipated mortalities from turbine passage with the mortalities that could occur as a result of elevated TDG due to spill and associated GBT effects. The assessment hypothesized that mortality due to controlled dissolved gas levels from the NMFS spill program would be less than mortality due to turbine passage.

The assessment methods required estimating turbine mortality under different river management (spill/no spill) schemes, and estimating mortality from TDG created by increased spill. Turbine mortality was then used as a benchmark for comparison with projected mortality from TDG under increased spill programs. At some level of TDG, juvenile mortality due to gas supersaturation will equal or exceed that due to turbine passage. Spill-generated TDG levels above that point will be increasingly detrimental to juvenile migrants.

Turbine mortality estimates were derived from 1992 smolt monitoring program data, which provided a measure of fish population size and timing. The numbers of fish passing through turbines were estimated by applying the fish guidance efficiencies identified in the Columbia Basin Fish and Wildlife Authority's Detailed Fishery Operating Plan to the population figures. The population numbers were also adjusted to reflect fish capture for the transportation program and for losses to the population from reservoir mortalities. Finally, the river project operations component of the assessment was chosen to represent three levels of spill:

1) Hydrosystem operated for power generation only (baseline, no spill)
2) Hydrosystem operated according to 1992 FCRPS Biological Opinion spill
3) Hydrosystem operated to 80% FPE (115% to 120% TDG spill caps)

Each operational scenario yielded an estimate of juvenile turbine mortality under the described conditions.

The estimates of mortality due to TDG were more difficult. In the mid-1990s, bioassays had determined lethal TDG levels primarily under shallow-water laboratory conditions, which are not representative of the conditions experienced by migrating juveniles. The Columbia River is sufficiently deep throughout the FCRPS that migrants could benefit from depth compensation for supersaturated conditions. In 1995, many fisheries scientists believed depth compensation was significant in determining fish responses to TDG.

Because of their depth limitations, the laboratory TDG bioassay data were not used in the 1995 assessment. Dissolved gas mortalities were estimated using the results of in situ field studies in which fish were exposed in live cages and held at specified depths. The exposures and amount of depth compensation experienced by the test fish were, therefore, more representative of the condition experienced by migrants. Dissolved gas mortality functions were calculated from data for coho, chinook, and steelhead exposed at representative depths, to gas levels ranging from 110% to 140% and for periods from 3 to 92 days (Ebel 1969; Beiningen and Ebel 1969; Ebel 1971; Meekin and Turner 1974; Blahm et al. 1975, 1976; Dawley 1986; and Toner et al. 1995). The mortality function for dissolved gas, developed statistically, described the percent of fish mortality as a function of TDG. The analysis also considered exposure duration, species, and depth. The data were fitted to a logistical model.

The risk model used by the agencies and tribes in 1995 is demonstrated in Figure 1, which plots turbine mortality (y-axis) against percent dissolved gas (x-axis). The calculations of mortality, in numbers of juvenile fish, estimated the difference in project mortality between a no-spill (maximum turbine passage and mortality) and an 80% FPE scenario (minimum mortality due to maximized spill). The difference in mortality between the two extremes was termed a mortality "ceiling," and represents the expected benefit of 80% FPE spill up to the gas cap, excluding TDG-induced mortality. The expected benefit in terms of number of fish is shown as a horizontal line in Figure 1. The sigmoid line in the figure is an example of a mortality function curve, which represents the estimated loss of fish due to TDG. The point where the turbine mortality line and the gas mortality curve intersect is where the mortality due to dissolved gas from spill equals the mortality due to turbine passage. That is, additional spill and resulting gas would be predicted by the model to kill more fish than would turbine passage.

A shortcoming of the risk assessment model is determining how to incorporate exposure time in the mortality function. The 1995 report therefore assessed risk in two time frames, i.e., the model assumed that dissolved gas mortality was either instantaneous at the project, or occurred after an exposure period equal to the travel time from Ice Harbor Dam to Bonneville Dam. Even with such an oversimplification, the dissolved gas concentration at which no further benefit could be achieved by increasing spill exceeded the 120% tailrace gas cap set by the FCRPS 1995 Biological Opinion.

The 1995 report concluded that spill provided a safe route of project passage compared with turbines, up to the spill levels that would generate a downstream gas equivalent to 120% to 125% TDG in the tailraces.

E.3.2 Adult Salmonid Assessment

The 1995 report estimated potential adult mortality due to elevated TDG levels for chinook, sockeye, and steelhead. Using published laboratory and field mortality data for those species, the assessment focused on a TDG range of 115% to 130% and on actual river conditions and spill levels during the spring and summer. The analysts made two assumptions: 1) there would be no

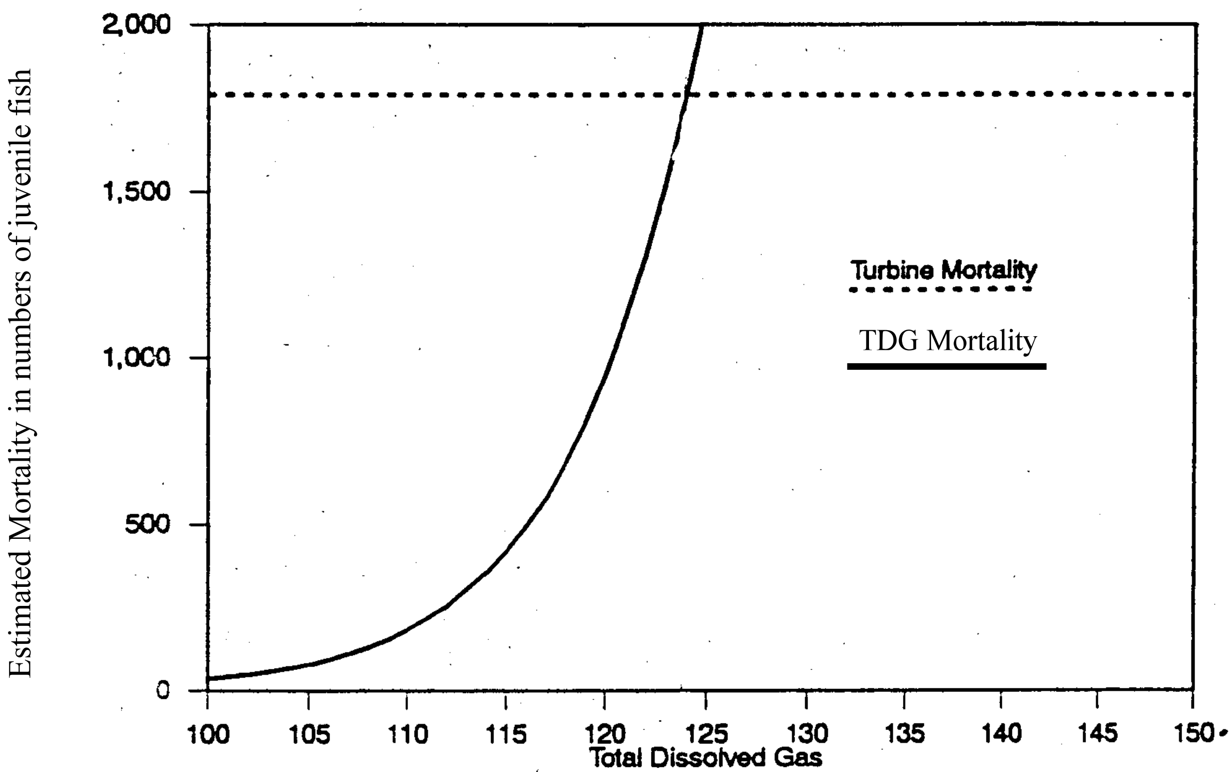

Figure E-1. Risk assessment model example.

dissolved gas-related mortality at gas levels less than 110%, and 2) only fish occupying water less than 3 meters deep would be vulnerable to GBT. The latter assumption factored in effects of depth compensation.

The model that was developed estimated the size of the population exposed, the exposure time, and the expected mortality for fish in three depth zones (0 to 1, 1 to 2, and 2 to 3 meters). Mortality was estimated by regression analysis for spring chinook, sockeye, and summer and winter steelhead.

The analysis projected no adult chinook, sockeye, or steelhead mortalities at 115% or 120% TDG, assuming depth compensation. Mortality for summer chinook and sockeye was predicted to increase between 125% and 130% TDG. The predicted mortality of steelhead at 125% and 130% was less than that of chinook and sockeye, because of the migration timing of the species.

Another step taken in this 1995 analysis considered the fate of the juveniles protected by an increased spill program, i.e., juveniles that were spilled and thus avoided turbine passage. The anticipated increase in numbers of juveniles was converted to an estimated survival-to-adult number. The adult equivalent estimate was also used to assess the impact of TDG on the adult population.

E.4 2000 TURBINE MORTALITY VERSUS SPILL MORTALITY ASSESSMENT

The 2000 FCRPS Biological Opinion analyzes the biological effects of many actions, strategies, and scenarios, separately or in concert. To assist in the biological analysis, a Biological Effects Team was formed. The team was one of five formed to assist in the Section 7 consultation process. It was agreed that the biological effects of juvenile salmonid passage measures, including spill, would be evaluated by the Biological Effects Team and NMFS using the SIMPAS model. The details of the biological effects analysis and the SIMPAS model are discussed in Appendix D.

The SIMPAS model is particularly appropriate for spill questions, because it accounts for successful passage through each route available to juvenile fish, including turbines, sluiceways, surface and conventional fish bypasses, and spillways. The model also accounts for juvenile fish transportation and reservoir passage. The model produces juvenile survival estimates at each project individually and systemwide. The model incorporates the latest qualitative and quantitative information on spill efficiency, fish guidance efficiency, turbine survival, bypass survival, spill/gas caps, spillway survival, sluiceway survival and diel passage patterns (NMFS 2000b,c,d,e).

The spill scenarios were analyzed for this assessment using the SIMPAS model. It was assumed that the 2000 FCRPS Biological Opinion reasonable and prudent alternative (RPA) spill program was fully implemented. The RPA condition was selected because the long-term TDG goal (i.e., over the next 10 years or so), as stated in Section 9.6.1.7.1 of the 2000 FCRPS Biological Opinion, is to reach the 110% standard in all critical habitat in the Columbia River and Snake River basins, including the mainstem. Achieving this goal in the long term still requires juvenile fish system survival levels to be consistent with the performance standards for the mainstem FCRPS hydropower projects (see Section 9.2.2.2.1 of the biological opinion).

The spill conditions in the SIMPAS model reflect current state water quality guidelines. TDG is 110% in Washington and Oregon. Each year since 1995, the states have temporarily waived the 110% limit and allowed spill to a gas level not to exceed 115% in project forebays or 120% in the tailrace. The modeled spill volumes are based on the current U.S. Army Corps of Engineers' estimates of spill expected to yield the above levels of TDG supersaturation. A 1995 water condition was selected for the spill studies as an approximate average water condition.[2] The 1995 water year resulted in involuntary spill only at McNary Dam.

For the present assessment, SIMPAS survival modeling was conducted for juvenile spring chinook (yearling), juvenile fall chinook (subyearlings), and juvenile steelhead migrants under 110% TDG spill levels and under 115% or 120% TDG spill levels. Additional spill at the 115% or 120% TDG levels would yield an improvement of 5.7% in inriver survival for juvenile spring chinook yearlings. The increases in inriver system survival are estimated to be 4.9% for subyearling chinook and 3.9% for juvenile steelhead.

E.5 SUMMARY OF BIOLOGICAL MONITORING SINCE 1995

The 1995 FCRPS Biological Opinion called for physical and biological monitoring programs to accompany implementation of the spill programs. The purpose was to track and record spill, dissolved gas, and effects on aquatic biota. The physical monitoring program deployed about 40 dissolved-gas saturometers at various forebay and tailrace stations throughout the FCRPS. Some monitoring stations were also established and operated by the Mid-Columbia Public Utility Districts (PUDs).

The biological component of the monitoring program required collecting and examining juveniles and adult salmonids for GBT. Juveniles are collected as the fish pass through the juvenile collection/bypass facilities at Lower Granite, Little Goose, Lower Monumental, Rock Island (a Mid-Columbia PUD project), McNary, and Bonneville dams. The fish are inspected for fin, eye, and lateral line signs of GBT. Adults are examined at Bonneville and Lower Granite dams. Adults have also been examined at the Priest Rapids and Three Mile (Umatilla River) dams. All adults are examined for signs of GBT in the fins and eyes. Detailed results of the physical and biological monitoring programs are reviewed in annual reports to the Oregon Department of Environmental Quality (ODEQ) (NMFS 2000a).

E.5.1 Results of Physical Monitoring Program, 1995 to 1999

The physical monitoring program results from 1995 to 1999 should be differentiated into two conditions to clarify the potential impact of the NMFS spill program on salmonids. The two spill conditions are 1) a program managed or planned to keep spill levels within 115% or 120% TDG, and 2) involuntary, or forced, spill conditions. The first condition is controllable; spill for fish

[2]Specifically, the 1995 modified April-to-August runoff volume at Lower Granite Dam on the Snake River was 22.4 million acre-feet (maf), or 98% of average, while the April-to-August runoff volume for the Columbia River at The Dalles was 86.1 maf, or 94% of average.

can generally be managed within the state water quality limits in average to below-average runoff conditions. The second condition is uncontrollable because it results from average to above-average runoff that creates high river flows beyond the hydraulic capacity of the FCRPS powerhouses. The differences in the two spill conditions are reflected in the percent of days during the spring and summer migration periods when TDG exceeds 120% and 130% in the tailraces of lower Snake and Columbia River dams. For example, 1995 was the only year during the period with near-average runoff. The percent of days exceeding 120% TDG in 1995 was only about 8%, and for 130% TDG, only about 2%. The exceedances were due to short periods of involuntary spill, and to lack of gas-abatement structures at Ice Harbor and John Day dams. Thus, for most of the 1995 migration period, gas levels were managed to below 120% TDG.

That was not the case for the higher runoff years of 1996 through 1999. In most of those years, flows exceeded hydraulic capacity and caused involuntary spill for stretches of days. The highest runoff years were 1996 and 1997, which experienced 130% and 155% of average runoff in the Snake River and 122% and 121% of average runoff in the Columbia River, respectively. The 1997 April-to-August runoff volume at Lower Granite Dam on the Snake River, for example, was the third highest since 1928. During these two years, the percent of days exceeding 120% and 130% TDG was about 48% and 15% to 22%, respectively. Again, the exceedances were due largely to involuntary spill. In 1998 and 1999, runoff was 112% and 119% of average in the Snake River and 98% and 118% of average in the Columbia River, respectively. The percent of days during the migration period exceeding 120% TDG ranged between 16% and 18%, respectively, with only one day in 1998 exceeding 130% TDG. Most exceedances were due to involuntary spill.

The tailraces of John Day and Ice Harbor dams, however, regularly exceeded the state 120% waiver limit from 1995 to 1997. Ice Harbor tailwater exceeded 130% almost 44% of the migration period in 1996, and the John Day tailwater exceeded that level about 48% of the time in 1997. Those levels were due largely to the high runoff volumes and flows that frequently exceeded the hydraulic limits of the projects, but also to lack of gas-abatement structures. Installing gas-abatement structures at both Ice Harbor and John Day dams in 1998 and 1999 contributed to the observed reductions in the gas levels in the tailwaters of those projects. The number of days when TDG levels exceeded the waiver level was reduced on average by about 50 days in 1998 and about 10 days in 1999.

E.5.2 Results of Biological Monitoring Program, 1995 to 1999

The biological monitoring program has been implemented each spring and summer since 1995. The results from 1995 to 1999 are evaluated and presented in the NMFS annual reports to ODEQ (NMFS 1996, 1997, 1998, 1999, 2000a). On capture, juvenile fish are anesthetized and examined for the presence and severity of GBT signs. The severity of the signs is ranked according to the criteria in Table E-1, with ranks 3 and 4 classified as severe.

Table E-1. Criteria for ranking prevalence and severity of gas bubble trauma signs (NMFS 1997).

Rank	Area Covered With Bubbles (%)
0	0
1	1 - 5
2	6 -25
3	26 - 50
4	> 50

GBT signs (bubbles and blisters in the fins, eyes, gills, lateral line, mouth, and skin) have been recognized since the late 1960s. However, no clear correlation has been made between the various signs and mortality. Although it is generally accepted that the proximate cause of death in fish is gill emboli (Maule et al. 1997), a nonlethal technique has never been developed to examine gill lamellae. Therefore, fin bubbles continue to be the sign conventionally used to monitor and rank for biological effects of TDG supersaturation.

An important application of the GBT ranking system is in managing the spill program. Early on, it was determined that action to reduce voluntary spill and TDG levels would be taken if more than 5% of the fish examined exhibited bubbles covering 25% or more (rank 3) of the surface of any unpaired fin, or if 15% of the fish showed any bubbles on unpaired fins. These are referred to as the spill program “action levels.” The action levels incorporate a margin of safety and are based on uncertainties raised in earlier research by the U.S. Geological Survey, Biological Resources Division (Maule et al. 1997a, 1997b). Those studies found that significant mortality did not occur in the test fish until approximately 60% of the exposed population exhibited bubbles in the fins or 30% displayed bubbles covering 25% or more of any unpaired fin. The action levels were then reduced primarily because the research results indicated a substantial uncertainty between fin bubble percentage and the onset of mortality.

The data in Table E-2 were reported in the 2000 NMFS annual report to the ODEQ. Reported are the number and percent of juveniles with severe GBT signs (rank 3 or 4) observed in fish collected during the past 5 years. Table E-2 shows that severe signs were observed primarily in 1996 and 1997. The management strategy for the spill program is to reduce spill in response to severe signs. That has never happened during managed (or voluntary) spill conditions. For example, in 1996 and 1997, when severe GBT signs were recorded, spill reduction was not an option because high runoff conditions exceeded the hydraulic capacity of FCRPS powerhouses. There were also six instances of severe or action-level signs in 1998. They occurred in the early part of the spill season, when flows were large and spill responsible for elevated TDG was due to involuntary conditions (Filardo, personal communication).

Table E-2. Summary of severe GBT signs monitored at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville dams.

		Severe GBT Signs	
Year	**Fish Examined**	**No.**	**%**
1995	71,230	0	0.00
1996	38,925	47	0.12
1997	42,751	117	0.27
1998	46,498	6	0.01
1999	25,184	0	0.00

From 1995 to 1999, the smolt monitoring program collected and observed 192,832 juvenile salmonids for GBT signs in the mainstem Snake and lower Columbia rivers. A total of 3,033, or 1.6%, showed some signs of GBT in their paired fins. The yearly incidence of signs was related to TDG exposure. For 1996 and 1997, higher levels of TDG were associated with higher percentages of GBT signs in salmonids (3.2% to 3.3%). Whereas in 1995, 1998, and 1999, with lower levels of TDG, the percentage of fish showing signs ranged from only 0.04% to 0.7%.

Figures E-2 and E-3 display the percent of sampled yearling chinook and steelhead in the lower Snake and lower Columbia rivers with observed signs of GBT relative to the TDG levels and the ranked response. It is apparent that few fish exposed to TDG levels below 120% exhibited GBT signs. However, fish with signs of GBT that were exposed to gas levels above 120% showed both an increasing incidence and severity. The more severe signs of rank 3 follow a similar pattern but do not begin to appear until TDG exceeds 116% to120%. Rank 3 signs become more prevalent above 131% TDG. The more severe signs affect only about 0.5% of the fish collected throughout the 5 years of the monitoring program.

Over the same 5-year period, steelhead sampled in the smolt monitoring program that displayed signs of GBT showed exactly the same trends in incidence and severity as did chinook. Rank 3 signs became more prevalent above 131% TDG and only affected about 1% of the fish collected during the 5 years.

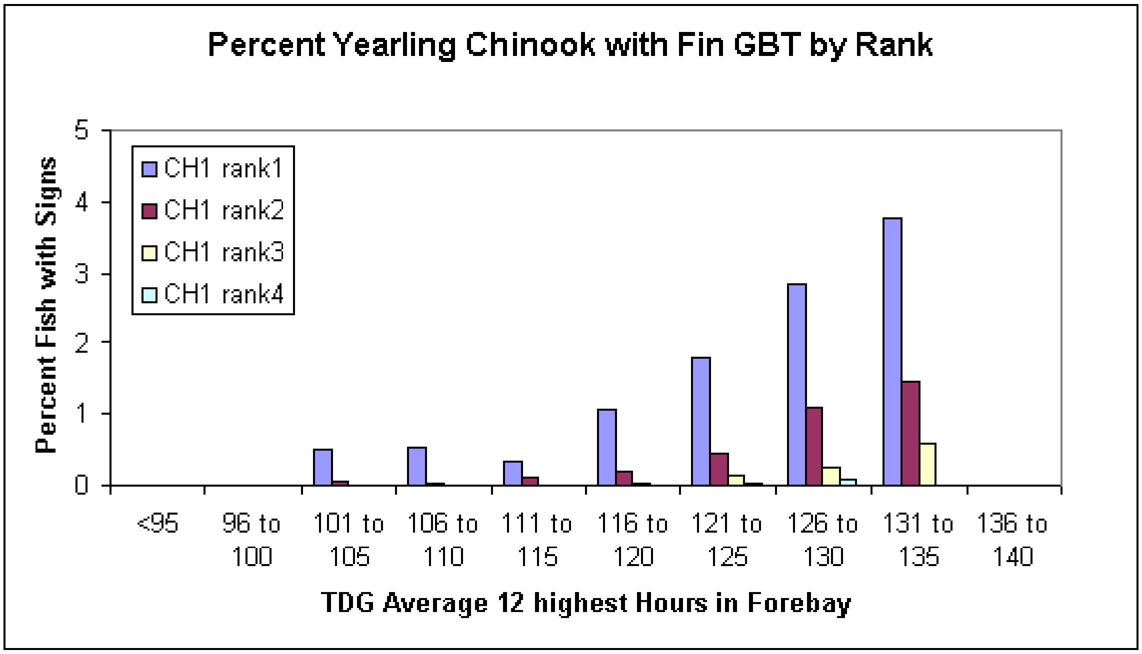

Figure E-2. Percent yearling chinook salmon examined for GBT from 1995 to 1999 that exhibited fin bubbles of rank 1 through 4 versus forebay TDG levels (average of 12 highest hours) measured the day the fish were examined (Rock Island Dam monitoring not included).

E.5.3 Adult Monitoring

Since 1996, adult fish have routinely been examined for the effects of TDG exposure during their upriver migration. The fish have been collected at Bonneville and Lower Granite dams, and less regularly at Ice Harbor, Priest Rapids, and Three Mile dams. Because of the high value of the adult fish and their potential for mortality due to handling, adult sampling for GBT is ancillary to other research on adult fish. The results of 4 years of adult fish monitoring are summarized in Table E-3.

As with juvenile monitoring, spring 1997 was the period of highest dissolved gas and the most significant degree of GBT in adult salmonids since the start of the spill program. In 1997, because of high runoff and forced spill conditions, TDG below Bonneville Dam was 135% or higher for 16 days, and above 130% for 24 days. During the spring and early summer, gas levels remained above 125% for an extended period in many sections of the river. Sockeye were most affected in 1997, with 15.6% of the fish collected at Bonneville Dam displaying signs of GBT. At Priest Rapids Dam, 4.2% of the collected sockeye were also affected. No sockeye were collected at Lower Granite Dam. During the same period, 0.5% of the chinook population was afflicted with GBT at Bonneville Dam, 0.1% at Lower Granite Dam, and 3.2% at Priest Rapids Dam. In the other years of monitoring (1996, 1998, and 1999), only a small number of fish collected at the sampling sites displayed signs of GBT. At Bonneville Dam, for example, none of the caught fish showed GBT signs.

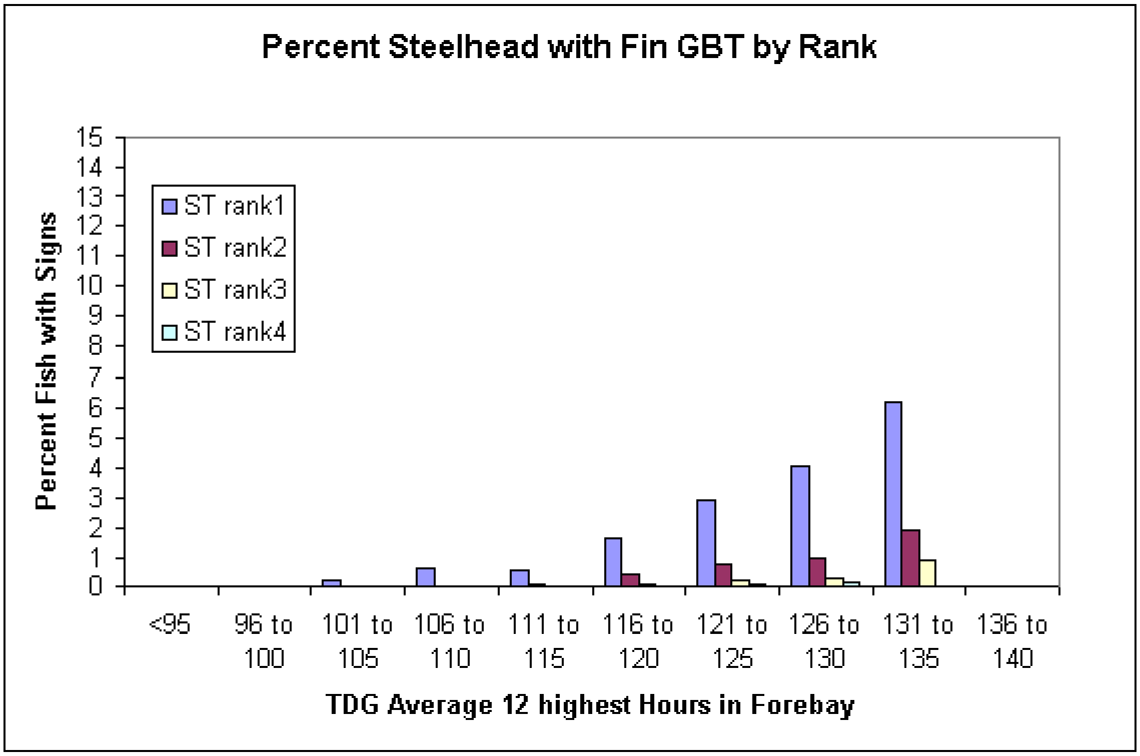

Figure E-3. Percent of steelhead examined for GBT from 1995 to 1999 that exhibited fin bubbles of rank 1 through 4 versus forebay TDG levels (average of 12 highest hours) measured the day the fish were examined (Rock Island Dam monitoring not included).

The action levels established by NMFS for adults are more stringent than those for juveniles. The adult levels stipulate reduction of spill if two or more fish are observed to have external signs of GBT in a single day at a sampling site. Action is also prompted if signs are found on one fish in two or more sampling periods at the same project. The results of the monitoring program show that the action levels were surpassed only in the high spill years of 1996 and 1997. However, the substantial involuntary spill in those years eliminated the ability of river managers to respond to the action levels by reducing spill and the associated TDG levels.

E.5.4 Resident Aquatic Species

The sensitivity of resident fishes and invertebrates to TDG supersaturation was investigated in the early 1990s. Species observed for GBT signs included suckers, sculpins, sticklebacks, and several minnows as well as crayfish, clams, and insect larvae. Gas exposure levels ranged from 117% to 130%. Only rarely were GBT signs observed (Toner 1993). It was concluded that resident fishes and invertebrates are relatively tolerant of elevated TDG.

Table E-3. Adult salmonid GBT recorded at FCRPS projects between 1996 and 1999.

Site	Species	Fish Examined	Fish With GBT Signs No.	Fish With GBT Signs %
1996				
Bonneville	Chinook	*	4	0.2
	Steelhead	*	3	0.1
	Sockeye	*	1	0.05
Lower Granite	Chinook	2652	4	0.1
1997				
Bonneville	Chinook	1042	5	0.5
	Steelhead	336	24	7.1
	Sockeye	648	101	15.6
Lower Granite	Chinook	6312	5	0.1
Priest Rapids	Chinook	280	9	3.2
	Steelhead	95	2	2.1
	Sockeye	852	36	4.2
1998				
Bonneville	Chinook	729	0	0.0
	Steelhead	260	0	0.0
	Sockeye	184	0	0.0
Lower Granite	Chinook	3755	4	0.1
1999				
Bonneville	Chinook	745	0	0.0
	Steelhead	273	0	0.0
	Sockeye	184	0	0.0
Lower Granite	Chinook	3755	4	0.1

*Total number of fish examined = 2026.

More recent studies have concluded that the current knowledge about TDG effects on resident fish allows reliance on a model to predict signs in resident species on the basis of physical measurements of TDG. Ryan and Dawley (1998) investigated the responses of resident fish held in net pens. They observed that a relationship could be developed to predict signs at various TDG levels for resident species. Shrank et al. (1998) developed an algorithm model that predicts GBT signs in resident fishes where continuous TDG monitoring is available. They concluded that extensive biological monitoring of resident species is unnecessary.

E.6 SUMMARY OF RESEARCH RESULTS

E.6.1 Mortality

Seasonal periods of high spill and gas supersaturation in the Columbia River basin system have been a problem for decades. The effect of high TDG on the aquatic species of the rivers is well documented (Beiningen and Ebel 1970; Ebel et al. 1975; Weitkamp and Katz 1980). The precise relationship between dissolved gas and fish mortality was unknown in the 1960s and 1970s. Early studies did, however, demonstrate a relationship between biological effects and TDG level, exposure duration, depth of exposure, water temperature, species, fish condition, and life stage (Ebel et al. 1975; Blahm et al. 1973; Dawley et al. 1975; Dawley and Ebel 1975; Blahm et al. 1975; Weitkamp 1976; Weitkamp and Katz 1980; Jensen et al. 1986).

Ebel et al. (1975) reviewed the findings of several bioassay studies and reported substantial fish mortality at 115% TDG after 25 days of exposure in shallow water. Blahm et al. (1973) recorded 98% (chinook) and 80% (coho) mortality at greater than or equal to120% TDG at a depth of 1 meter. However, in 2.5 meters at the same TDG level, mortalities were reduced to 8.7% and 4.2%, respectively. If fish are allowed access to deeper water during the tests, mortality will be observed at TDG levels greater than 120% after more than 20 days. Dawley et al. (1975) found that all species tested in deep-water tanks reached 50% mortality in 24 hours at 130% TDG, but had no recorded deaths at 110% TDG in 24 hours.

Efforts to protect fish in the late 1960s and through the 1970s focused on determining a lethal TDG threshold. Most of the research investigated dissolved gas levels ranging from 110% to 140% TDG supersaturation. However, many of the early studies were conducted in shallow laboratory tanks and found mortalities at 115% TDG after 3 to 4 weeks of exposure (Dawley and Ebel 1975). On the basis of those early bioassays, the EPA set the dissolved gas standard at 110% TDG. However, it has been suggested that defensible gas limits for a free-flowing river environment could be set as high as 120% TDG (Weitkamp and Katz 1980).

E.6.2 Gas Bubble Trauma Signs

Columbia River fish managers realized early that the effects of TDG on fish populations could not be assessed merely on the physical measurements of dissolved gas. Knowledge of the incidence, severity, and progression of GBT signs was essential.

An important finding in early research was that death from TDG exposure can occur in the absence of any external signs (Meekin and Turner 1974, Weitkamp 1975, and Bouck et al. 1976). Signs of GBT were found to be most severe in lower, marginally lethal gas supersaturation exposures (Bouck et al. 1976). Several researchers observed that fish that do not die from GBT may undergo a reduction in prevalence and severity of signs on return to air-equilibrated water (Meekin and Turner 1974, Blahm et al. 1973, Weitkamp 1974, Knittel et al. 1980, Dawley and Ebel 1975). Ebel et al. (1975) also noted that the signs of GBT disappear after death. The results from these early studies indicate that it is necessary to monitor migrants for signs of GBT as the biological threshold indicator of TDG supersaturation stress. However, there is no clear set of signs, or a clear time correlation between TDG level and exposure duration, that allows impending fatality to be predicted.

The signs of GBT in adults are like those observed in juveniles. They include emphysema, circulatory emboli, tissue necrosis, and hemorrhages in brain, muscle, gonads, and eyes (Weitkamp and Katz 1980). Nebeker et al. (1976) found that death in adults was due to massive blockages of blood flow from gas emboli in the heart, gills, and other capillary beds. Investigators in the 1970s reported many and varied lesions in fish exposed in the 115%-to-120% TDG range in shallow water. At higher gas exposures, e.g.,120% to 130% TDG, death frequently ensued before GBT signs appeared (Bouck et al. 1976). External signs of GBT, e.g., blisters forming in the mouth and fins of fish exposed to chronic high gas, often disappeared rapidly after death. The signs were largely gone within 24 hours (Countant and Genoway 1968).

Recent studies have pursued the relationship of exposure to TDG supersaturation and the presence, progression, severity, and relevance of GBT signs, especially as related to the monitoring program. Maule et al. (1997) found that no single GBT sign can be relied on as the sole precursor of lethal conditions in the field. However, GBT signs did worsen with longer exposure to the conditions. However, it is necessary to better understand the severity and prevalence of signs in several tissues and relate them to exposure time and adverse reactions. The conventional signs used in GBT studies and monitoring are the lateral line, fins, and gill filaments.

According to Maule et al. (1997a), Elston et al. (1997), Hans et al. (1999), and Mesa et al. (1999), each of the following tissues manifests unique tissue bubble characteristics:

Lateral line	Earliest tissue to display signs
	Signs may disappear quickly
	Progressive worsening with time
	Low degree of individual specimen variation
	Progressiveness of sign is indicator of exposure severity
	May not be relevant in chronic exposure to low TDG
Fins	Bubbles may not develop in acute exposure
	High prevalence in most exposures
	Progressive worsening with time
	Bubbles are persistent
	Quantitative ranking of severity difficult
Gills	Bubbles proximate cause of mortality
	Little progression with time
	High degree of variation
	Poor predictors of severity
	Difficult to observe and quantify
	Bubbles may collapse easily on recompression

Maule et al. (1997) reviewed the implications of their findings with lateral line, gill, and fin signs as they might relate to monitoring programs. Lateral line bubbles were often the first observed. They showed progression with exposure and displayed little variation between specimens, but developed slowly under chronic, low gas treatments. Gill bubbles were usually the likely cause of death but did not progressively worsen. Individual variations were high in gill bubbles.

Although fin bubbles are prevalent and worsen with time, the practical use of fin bubbles as an indicator is hindered by lack of a rigorous quantitative method for evaluating severity. Mesa et al. (1999) summarized the findings of studies of GBT signs. Mesa pointed out the usefulness of the progressive nature of signs to monitoring programs, but also highlighted the following impediments:

1. Variability in persistence of GBT signs
2. Inconsistent relation of GBT signs to mortality
3. Insufficient knowledge of relation between exposure history and development of GBT signs
4. Extreme amount of variability of GBT signs

In spite of this, Maule et al. (1997) observed that GBT is most often progressive, and that its severity is a function of TDG level and exposure time. If a group of fish is exposed to TDG supersaturation for a sufficiently long period, the outcome is not in question. Signs of GBT will develop. Therefore, careful, rigorous monitoring of a population of migrants as they move through the FCRPS will detect GBT. If TDG is low and passage time exceeds the threshold time for development of signs, the juveniles will have moved beyond dissolved gas effects of the river.

E.6.3 Depth Compensation

Gas solubility increases with increasing pressure. For each meter of depth there is a 10% reduction in the TDG saturation level relative the surface saturation (Weitkamp and Katz 1980). By the mid-1970s, researchers had gathered information suggesting that depth compensation occurs and has the biological effect that gas solubility calculations would predict. Weitkamp (1976) observed that juvenile salmonids held in live cages up to 4 meters deep in the Columbia River suffered no mortality in test ranges from 119% to 128% TDG. Dawley et al. (1975) conducted tests in a 10-meter-deep tank and found no steelhead mortality at 130% TDG and no spring chinook mortality at 133 % TDG. GBT signs were noted in both species, however.

Technological advances provide ways of studying depth compensation more closely. Using a pressure-sensitive radio frequency tag accurate to 0.3 meters of the true depth, Maule et al. (1997) observed that salmonids may migrate at protective depths. In that pilot study, few fish were successfully tagged and tracked, and the data were insufficient for statistical analysis. However, the results suggested that the depth of the tagged fish would compensate for a surface TDG level of up to approximately 124%.

In subsequent years, Beeman et al. (1998, 1999) employed depth-sensitive radio tags to determine the depths of juveniles from Ice Harbor to McNary Dam. The 1997 studies indicate that fish were tracked at depths between 1.8 and 2.5 meters in water with a surface TDG level of 120%. The recorded depths would have provided protection and reduced the risk of GBT. The next year, the median depth of juveniles in McNary pool was sufficient to protect fish from TDG levels of between 117% and 124%. This level of depth compensation is enough to negate predicted mortalities from the mid-1970s laboratory studies conducted in shallow water. It also may explain why the annual biological monitoring program detects fewer GBT signs than might be expected. The authors concluded that a voluntary spill program with gas caps of 115% in forebays and 120% in tailraces can be expected to prevent gas bubble trauma in juvenile chinook and pose little threat to the more sensitive steelhead.

Gray and Haynes (1977) reported that spring and fall chinook adults implanted with pressure-sensitive radio transmitters swam deeper in gas supersaturated water than in air-equilibrated conditions. They concluded that 89% of the test fish migrated at a depth providing compensation for gas levels that would normally prove lethal.

More recent studies have employed a data storage radio tag to record both the depth and temperature history of migrating adults. Preliminary analysis of results indicate that tagged fish migrate in the depth range of 1.5 to 4 meters, some deeper than 4 meters. Thus, it appears that most of the chinook or steelhead adults may be negotiating the lower Snake River at compensatory depths for gas levels to at least 130% (Bjornn, personal communication, 2000).

E.7 CONCLUSIONS

A risk assessment was described earlier as a comparison of alternative paths to consider the probability of adverse action. Using the SIMPAS model, it was determined that an increase of 4% to 6% in system survival of juveniles would result from spill up to the biological opinion gas cap, i.e., 120% TDG, as compared to spilling to the 110% water quality standard. The question is whether there is any adverse effect resulting from the 10% increase in TDG. The potential adverse effects of this TDG increase can be judged by reviewing the findings of the 1995 report, the information gained in the last 5 years of monitoring, and relevant research.

The 1995 risk assessment estimated turbine mortality and compared it with a TDG mortality curve. The report concluded that, at the point where projected dissolved gas mortality equaled the lethality of turbine passage, higher TDG levels due to additional spill beyond a certain point would be counter-productive. That point ranged between 120% and 125% TDG. The assessment was conducted for spring, summer, and fall chinook, sockeye, and steelhead—the salmonid species of concern. The 1995 report concluded that a spill level of 120% to 125% TDG represented a conservative, controllable, and reasonable risk compared with turbine passage. Since a managed biological opinion spill program will result in gas up to 120% TDG, spill to this gas level is expected to provide a safer route of project passage than turbine passage.

The 1995 report also strongly urged establishing monitoring programs to track dissolved gas and monitor for signs of GBT. The results of 5 years of physical monitoring show that TDG generated as a result of implementing the spill program is adequately detected and recorded. When water conditions allow voluntary spill to increase FPE, the spill and resulting dissolved gas can be managed to comply with the temporary state waivers. In periods of involuntary spill, the sensitivity of the monitoring system records the frequency, intensity, and duration of high levels of gas supersaturation, as in 1996 and 1997. The physical monitoring system also demonstrates the beneficial effects of the construction and operation of gas-abatement structures. For example, after spillway deflectors were built at Ice Harbor and John Day dams, their gas-abating effects were reflected in the physical monitoring data.

The biological component of the 5-year monitoring program is consistent with TDG records. When the TDG exceeds the waiver limits, a biological effect is recorded in both the smolt and adult monitoring program (Tables E-2 and E-3). For example, severe signs (rank 3) of GBT were restricted to the years 1996 and 1997 during the periods of highest involuntary spill, which resulted in TDG levels of 130% or more on many days. Although severe signs have been noted in the monitoring program, such instances have been rare and confined to periods of involuntary spill when gas levels are greater than 120% TDG.

GBT in juvenile salmonids is observed at all gas levels. Even at a relatively low gas supersaturation level of 110%, signs can develop if the exposure is long and the water is shallow. However, based on 5 years of data from the biological monitoring program, the average incidence of GBT signs has been low. The accumulated data on GBT in chinook and steelhead show few GBT signs below 120% TDG. When fish with signs are exposed to gas levels above120%, the incidence and severity of GBT signs increase. A similar pattern is observed in fish with the more severe ranks 3 and 4 signs. Only few fish with severe GBT signs are detected until TDG approaches 130%, and the prevalence of signs does not begin to increase until TDG is between 121% and 125%. The overall number of fish affected with GBT signs proved to be less than originally assumed in the 1995 report.

The monitoring program for adult salmonids shows a similar relationship between gas bubble signs and TDG. For example, when the inriver TDG level is below 120%, few adult fish—in some cases none—display signs of GBT. Oregon and Washington used that information, coupled with the extreme importance of adult migrants to salmon recovery efforts, to dispense with continued adult monitoring (and associated handling) requirements in their 1999 water quality waiver stipulations. Investigators observe adult tolerance to TDG and hypothesize that it is attributable to the migration depth of adult salmonids. The depth-sensitive radio tags being used in adult migration studies now corroborate that adults migrate at depths up to 4 meters and find depth compensation protection from GBT. Thus, NMFS believes that the 120% tailrace gas cap recommended by the 1995 FCRPS Biological Opinion places no special TDG burden on adult migrants.

The results of the 1995-to-1999 monitoring program are consistent with reports in the literature on dissolved gas and gas bubble disease research. In the late 1960s and in the 1970s, studies used dissolved gas exposures in the 110%-to-140% TDG range. In deep-tank or field studies, few effects were noted below 120% TDG, unless the exposure periods were very long (weeks).

From analysis of the biological monitoring program, NMFS concludes that biological monitoring of GBT signs can continue to be used to indicate dissolved gas exposure in adult and juvenile salmon migrants. The monitoring program indicates that the prevalence of GBT signs in the adult and juvenile salmonid migrant populations is well below the action levels supported by GBT mortality research, as long as TDG levels are kept below the levels recommended in the 2000 FCRPS Biological Opinion.

NMFS also concludes that the apparent contradiction between the current 110% TDG water quality standard limit and the biological opinion TDG limits is explained as an effect of depth compensation in migrating adult and juvenile salmonids. Finally, NMFS concludes that the risk associated with a 10% exceedance of the 110% TDG standard is more than compensated for by the improvement of an estimated 4% to 6% in FCRPS passage survival for juvenile salmon. NMFS finds little evidence that this survival improvement would be reduced by GBT-related mortality.

It should be kept in mind that the present assessment narrowly focused on salmonid migrants in the relatively deep mainstem reaches of the Columbia and Snake rivers, and was set against the mitigating factor of improved system passage survival. Applying the conclusions toward a change in national or state water quality standards would be inappropriate without additional research and monitoring data on other aquatic species and habitats.

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